NOAA Technical Report NESDIS 54

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EVALUATION OF DATA REDUCTION AND COMPOSITING OF THE NOAA GLOBAL VEGETATION INDEX PRODUCT: A CASE STUDY

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ABSTRACT. Data acquired by the Advanced Very High Resolution Radiometer (AVHRR) onboard the TIROS/NOAA series of satellites are spatially degraded from a 1 km resolution at nadir (LAC) to several coarser resolutions. Global Area Coverage (GAC) data are processed onboard the satellites and have a resolution of approximately 4 km. Global Vegetation Index (GVI) data are processed from sampled GAC data and have a resolution of approximately 15 km. The objectives of this study were to examine the effects of spatial degradation of NOAA AVHRR data on monitoring of land surface or related processes over large areas and to examine alternative procedures for computation and compositing of the GVI data product. → (over)

Comparisons of county and climatic division averages of the various resolutions of vegetation index data indicated that differences existed between the examined resolutions and sampling algorithms included in this study. A portion of the observed differences, however, was not due to the data reduction algorithms utilized but to shifts in county and climatic division boundaries as a result of the mean values of the vegetation index computed for the counties with the GAC data. The average difference between an ND value computed for a county at GAC and LAC resolutions was usually less than 0.01. Similarly, the GVI1 (current single GAC sample algorithm), GVI2 (modified average of all GAC samples algorithm), and GAC data provided essentially the same mean vegetation index values as LAC for the examined climatic division.

Vegetation index (VI) data derived for the climatic divisions computed with the GVI1 algorithm were more representative of the LAC and GAC data than were the VI data computed with the GVI2 algorithm. The range and distribution of the GVI1 data were more similar to that of the LAC and GAC data than were the GVI2 data. Thus, the results of this study suggest that NOAA continues to use the current algorithm for data reduction of the GVI product rather than an average of all GAC samples within a GVI pixel.

Evaluation of the weekly composite process supports previous research that observed a systematic bias in the scan angles of the satellite selected for the weekly composite due to the current (difference vegetation index) composite algorithm. Zenith angles selected by the present and modified (normalized difference) composite algorithms differed for greater than half of the observed weeks for the twelve sites examined in this study. The similarity of zenith angle selection by the two examined algorithms was as great

as 80% for the 10 composite weeks examined. The similarity of selected angles was as low as 20% of those weeks evaluated. Zenith angles in the backscatter direction were favored by the difference index algorithm compared to the normalized difference index, which appeared to favor selection of zenith angles in the forward scatter direction.

In summary, differences existed between the vegetation index values computed for the examined data resolutions, however, a portion of the observed difference was not due directly to reduction of the satellite data. The mean values of the low resolution (GAC or GVI) data were representative of the full resolution data. Thus, low resolution data ~~utilized~~ used in monitoring activities would likely provide the same results as full resolution data (LAC). The difference index would be the recommended algorithm for satellite zenith angle selection if advantages exist for selection of backscatter views of vegetation from satellites.

I. INTRODUCTION

Data Reduction

Current and future data derived from satellite platforms will be available at a variety of spatial, temporal, and spectral resolutions. The amount of data available to researchers is often more than required or can be utilized and thus, data reduction algorithms are applied. Temporal degradation includes weekly or greater composites of daily data (e.g., Tarpley et al., 1984). Spectral degradation includes combinations of two or more wavebands into fewer bands of data (e.g., normalized difference or greenness vegetation indices; Perry and Lautenschlager, 1984). Spatial degradation includes spatial averaging or sample selection that reduces the amount and resolution of the data over an area.

Visible (0.58 - 0.68 µm) and near-IR (0.72 - 1.0 µm) data acquired by the Advanced Very High Resolution Radiometer (AVHRR) on board the TIROS/NOAA series of satellites are spatially degraded from the 1 km resolution at nadir to several courser resolutions. Global Area Coverage (GAC) data (Kidwell, 1986) are processed on board the satellite and have a resolution of approximately 4 km. Global Vegetation Index (GVI) data (Kidwell, 1990) are processed from GAC data that have been transmitted to Earth and have a resolution of approximately 15 km.

The often overwhelming amount of data available for large-area monitoring of land surface processes often leads to the use of spatially degraded data (i.e., NOAA's GAC or GVI data). Additionally, there are applications of remotely sensed data that require multitemporal sampling within specific geographic or political boundaries for monitoring of a land surface or related process. Eidenshink et al. (1989) utilized 1 km AVHRR data averaged within U.S. county boundaries for applications in fire-fuel models. Gallo and Flesch (1989) utilized NOAA GVI data averaged within U.S. crop Reporting Districts for comparison with crop phenology. Gallo and Heddinghaus (1989) also utilized NOAA GVI data, averaged within U.S. Climatic Divisions for comparison with weekly climatic data. Global climatic models require data averaged over areas defined by several degrees of latitude and longitude (e.g., 4.5^{o} by 7.5^{o} for NCAR Global Community Model; Dickinson et al., 1986).

The spatial degradation of data from the Landsat Multispectral Scanner (MSS) resolution of 79 m to the NOAA AVHRR 1 and 4 km resolutions has been examined for specific land surface areas for single (Justice et al., 1989) and multiple dates (Townshend and Justice, 1988). Justice et al., (1989) also examined alternative methods to NOAA's current processing of 1 km data to GAC resolution. Generally, within each study, a decreased variability in vegetation index values was observed as spatial resolution decreased. Analysis by Justice et al. (1989), of spatially degraded data for Superior National Forest in Minnesota, indicated an increase of the normalized difference vegetation index (ND) of 5.8% as spatial resolution was degraded from 0.083 to 4 km. This increase could be attributed to the lack of detection of small lakes (ND values of zero or less) at the 4 km compared to .083 km

resolution data. Spatial degradation from 0.5 or 1 km to 4 km only increased ND by 0.9 and 0.5% respectively. These results, as well as the positive results observed in applications of the data (e.g. Gallo and Flesch, 1989) suggest that reduced resolution data may be adequate for land process applications over large areas.

Data Compositing

The scanning characteristics of the AVHRR present a capability for monitoring large areas (swath width approximately 2400 km), however, the zenith angles associated with the wide view result in a sensor view of the earth while orientated towards (forward view) and away (backward view) from the sun. Data presented in an analysis of 40 km resolution visible and near-IR AVHRR data (Gutman, 1987) indicated that the current GVI compositing algorithm may systematically bias (in favor of backward views) the solar zenith angle selection associated with the weekly composited visible, near-IR and vegetation index data. The current method of mapping daily GAC data to the GVI grid may also bias the zenith angle selection. The last GAC sample that is mapped to a GVI pixel is retained on a daily basis (Kidwell, 1990). Due to this mapping process, a specific surface location observed in two successive orbits would have data retained from the second (more backward) view of the surface.

The objectives of this study were to examine the effects of spatial degradation of NOAA AVHRR data on monitoring of land surface or related processes over large areas. Secondary objectives included examination of the GVI data sampling and compositing procedures. While GAC processing occurs on board the satellite, GVI processing occurs at a NESDIS facility in suburban Washington D.C. and can be modified. A second data reduction procedure for GVI data was evaluated for the GVI data and compared to 1 km, 4 km (GAC), and current GVI vegetation index data. Two vegetation index composite algorithms were evaluated with 1 km resolution data for satellite zenith angle selection differences.

II. MATERIALS AND METHODS

Data Reduction

Weekly 1 km (LAC) resolution composites of the normalized difference vegetation index (ND = (near-IR - visible)/(near-IR + visible)) derived from calibrated NOAA AVHRR reflectance data (Eidenshink et al., 1988) were resampled to produce GAC and GVI resolution data sets. A GAC pixel is the average derived from a one by four pixel sample of LAC pixels. One sample is skipped per row of data between computation of each GAC pixel. Additionally, two rows of data are skipped (Figure 1a) before continued computation of GAC pixels (Kidwell, 1986; Kidwell, 1990) Thus, each GAC pixel represents a 3 by 5 km region (at nadir) although the data are derived from a 1 by 4 km area.

Justice et al. (1989) observed that the ND computed for a GAC pixel from the ND values of LAC pixels may differ from a GAC ND value computed from GAC pixels of visible and near-IR data (i.e. visible and

near-IR averaged over the four LAC pixels prior to computation of ND). NOAA computes GAC data on board the satellite, thus, GAC visible and near-IR data are utilized in computation of the ND at the GVI resolution. A comparison of the ND values computed with the two methods of GAC computation (average ND over 4 pixels or average visible and near-IR with subsequent computation of ND) for one composite week of our data revealed little difference between the two methods. The ND values of the GAC resolution data computed with both methods were identical for greater than 30% of the pixels in our study area (total 118,827 GAC pixels). Greater than 90% of the pixels displayed a difference less than +/- 0.02 (ND data on a scale of -1.00 to 1.00). The GAC ND values of this study were computed as the average of the ND values of four LAC pixels as this method saved computational time and presented little difference from the alternative method.

GVI data processed by NOAA (Kidwell, 1990) consist of GAC resolution data that are mapped to a GVI pixel (aerial coverage approximately 15 by 15 km). The data of the last GAC pixel mapped to a GVI pixel are retained each day. Thus, the data of the GVI pixel are derived from a single sample of those GAC pixels within the GVI pixel area (Figure 1). This study included the NOAA GVI computational procedure (GVI1) and a second method of computation of GVI pixels (GVI2). The GVI2 sample was computed as the mean value of all GAC pixels (15 utilized in this study) within the GVI coverage area.

The region included in the composite data was the Northern Great Plains of the United States (approximately 37 to 50 ^{o}N and 94 to 108 ^{o}W). The study area includes a wide variety of land surface features. Agricultural areas within the study region include land planted with corn, soybeans, wheat, and sorghum. Grasslands, forests, lakes, rivers, urban areas, and a portion of the Rocky Mountains are all included in the region.

Briefly, from 29 March through 31 October 1988 NOAA-AVHRR data were acquired by a reception station at the U.S. Geological Survey's EROS Data Center in Sioux Falls, SD. Daily data for the Northern Great Plains were visually screened and scenes that were primarily cloudless within the region were retained for a weekly composite. This composite product was based on the daily normalized difference vegetation index (ND) values;

$$ND = (\text{near-IR} - \text{visible})/(\text{near-IR} + \text{visible}),$$

such that for each pixel the data associated with the maximum ND value was retained in the weekly composite. This composite differs from the NOAA/NESDIS GVI composite procedure as the retained data of that product are based on the daily difference index;

$$\text{Difference index} = (\text{near-IR} - \text{visible}).$$

Data reduction analyses utilized the weekly composites based on ND as these data were readily available and not expected to affect the results of comparisons of different data resolutions.

Five weeks of the weekly ND composite data were included in this

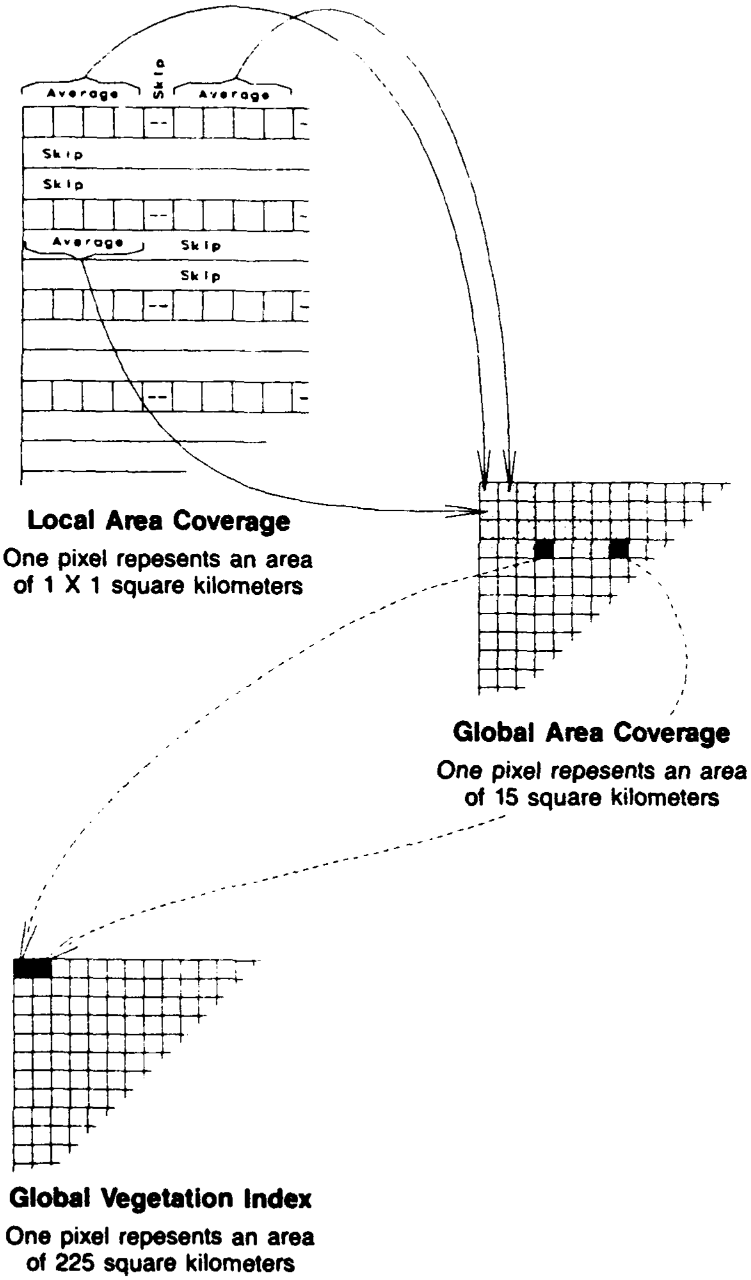

Figure 1. Examples of data sampled for NOAA Global Area Coverage and Global Vegetation Index products.

study. The five consecutive weeks began with 24-30 May 1988 and ended with the 7-day interval of 21-27 June 1987. Mean and standard deviations of the ND data for each week were computed for U.S. counties (LAC and GAC) and climatic divisions (LAC, GAC, GVI1, and GVI2) within the study area. The Land Analysis System (LAS, 1990) software developed jointly by NASA and the U.S. Geological Survey was utilized for the image processing included in this study.

A portion of the observed difference in mean ND values computed for the counties (or climatic divisions) included in the study is attributed to shifts in the boundaries of the counties between the resolutions of data (Wehde, 1982), as compared to loss of information due to the data reduction algorithms utilized. The observed difference in ND for the two resolutions was examined, however, statistical tests on the significance of these differences were not included in this study.

Analyses of the data included comparisons of the different resolutions on a weekly basis. Single composite data of individual counties and CD's, as well as week-to-week differences in the ND data for the various resolutions, were compared. Week-to-week comparisons utilized t-test analyses as only data of a similar resolution were compared for the two-week intervals.

Data Compositing

Daily visible and near-IR data used to compute the five weekly composites utilized in the data reduction analyses were combined with the daily data of the five subsequent weekly composite intervals to examine the influence of composite algorithms on satellite scan angle selection. Weekly composites were computed for 12 sites of varied vegetation based on the difference and normalized difference vegetation indices. Vegetation index values and scan angle selection were evaluated for the composites based on the two indices.

III. RESULTS AND DISCUSSIONS

Data Reduction

i. LAC, GAC, and GVI Comparisons: Entire Study Area

The means and standard deviations of normalized difference vegetation index (ND) values for the entire study area were similar throughout the 5 weeks of analysis (Table 1). The number of pixels included in the entire study area were 1,781,190 for the LAC images, 118,827 for the GAC images, and 7,938 for the GVI images.

Table 1. Mean, standard deviation, and coefficient of variation of the ND values for the entire study area by composite week and spatial resolution.

Composite Interval	Resolution	ND Mean	ND s	ND c.v. (%)
24 - 30 May (week 9)	LAC	.27	.113	41.8
	GAC	.27	.110	40.7
	GVI1	.27	.110	40.7
	GVI2	.27	.100	37.0
31 May - 6 June (week 10)	LAC	.35	.112	32.0
	GAC	.34	.109	32.0
	GVI1	.34	.110	32.3
	GVI2	.34	.099	29.1
7 - 13 June (week 11)	LAC	.30	.116	38.7
	GAC	.29	.117	40.3
	GVI1	.29	.118	40.7
	GVI2	.29	.107	36.9
14 - 20 June (week 12)	LAC	.30	.124	41.3
	GAC	.30	.120	40.0
	GVI1	.29	.121	41.7
	GVI2	.30	.111	37.0
21 - 27 June (week 13)	LAC	.28	.127	45.4
	GAC	.28	.124	44.3
	GVI1	.28	.125	44.6
	GVI2	.28	.115	41.1

The mean ND values were similar for the four resolutions. The GVI2 data displayed smaller standard deviations and coefficients of

variation, however, due to the greater spatial sampling of this data compared to the others.

The proportion of data for each of the four resolutions was examined by specific ranges of ND (Table 2). Proportions of the LAC, GAC, and GVI1 within the examined ranges of ND were similar for most of the composite weeks. The greatest proportion of data was, as expected, near the mean value for each of the resolutions within each

Table 2. The proportion of data for each of the four resolutions within the specified ranges of ND.

sample	<0.0	0≤.15	.16≤.25	.26≤.35	.36≤.45	>.45
			week 9			
LAC	.10a†	12.94a	30.58a	32.54a	16.68a	7.16a
GAC	.12a	12.08a	30.96a	34.73b	15.40b	6.71a
GVI	.13a	12.27a	30.75a	34.87b	15.22b	6.78a
GVI2	.01a	10.18b	32.31b	37.72c	14.19c	5.59b
			week 10			
LAC	.11a	2.89a	16.46a	29.85a	31.72a	18.97a
GAC	.11a	2.71a	16.63a	32.00b	30.82ab	17.73b
GVI	.16a	2.83a	16.88a	31.58b	30.71b	17.84b
GVI2	.00a	1.54b	16.39a	32.57b	33.60c	15.90c
			week 11			
LAC	.27a	5.94a	28.69a	29.84ab	23.56a	11.70a
GAC	.31a	7.82b	27.90a	30.21ab	22.21b	9.85b
GVI	.35a	8.20b	30.15b	29.25b	22.46b	9.59b
GVI2	.10a	6.42a	30.52b	30.80a	24.51a	7.65c
			week 12			
LAC	.06a	11.38a	24.55a	26.63a	25.67a	11.71a
GAC	.05a	10.58a	25.27a	28.50b	24.96a	10.64b
GVI	.10a	10.90a	25.24a	28.12b	24.93a	10.71ab
GVI2	.00a	8.18b	27.43b	29.03b	26.90b	8.46c
			week 13			
LAC	.25a	16.89a	24.42a	23.24a	25.28a	9.92a
GAC	.25a	16.13a	25.02a	24.08b	24.90a	8.99ab
GVI	.34a	16.48a	25.22a	24.02ab	25.29a	8.65b
GVI2	.08a	13.73b	27.75b	24.85b	26.82b	6.77c

† values with same letter (a, b, or c) indicate similarity of proportions within 1%.

examined week (Table 1). The GVI2 sampling method displayed, as expected, greater proportions of data near the mean, and less within the low and high ranges of the data, compared to the other sampling algorithms. The proportions of GVI2 data within the examined ranges differed from those of the LAC or GAC resolutions to a greater extent than the GVI1 data.

ii. County LAC and GAC ND Value Comparisons.

The greatest difference between the mean county ND values of the LAC and GAC data occurred in week 11 (Table 3) when the mean of the differences was nearly 0.01 (values in table have been multiplied by 10^2). The average difference between an ND value computed for a county at GAC and LAC resolution was usually less than 0.01.

Table 3. Mean ND values of LAC and GAC resolutions, and their differences, for the counties included in the study (n=544).

week	sample	mean county ND values				ND difference
		max	min	mean	s	($X\ 10^2$)
9	LAC	.50	.11	.30	.061	.156
	GAC	.43	.16	.30	.055	
10	LAC	.55	.18	.37	.060	.374
	GAC	.50	.22	.37	.055	
11	LAC	.52	.13	.32	.059	.978
	GAC	.45	.17	.32	.052	
12	LAC	.52	.11	.32	.060	.258
	GAC	.46	.17	.31	.053	
13	LAC	.51	.13	.31	.059	.171
	GAC	.45	.17	.31	.054	

Detection of changes in vegetation condition, seasonally or week-to-week, is often considered a requirement for monitoring activities. Week-to-week comparisons of county ND values were made individually for the LAC and GAC resolutions, thus, the differences due to boundary shifts between resolutions was not a limitation to the analysis. The number of counties that displayed detectable differences in ND values varied between the examined weeks (Table 4). The LAC resolution data consistently permitted greater detection of week-to-week changes in county ND values compared to the GAC

resolution. The LAC resolution ND values, for the four pairs of weeks examined, permitted detection of weekly differences in 86 to 98% of the counties. GAC resolution ND values permitted detection of weekly differences in 69 to 92% of the counties over the four pairs of weeks examined.

Table 4. Number of counties (total of 544 examined) with week-to-week significantly different values of ND.

	paired weeks examined			
resolution	9-10	10-11	11-12	12-13
LAC	530	518	518	470
GAC	502	470	442	376

iii. Climatic division LAC, GAC, and GVI ND value Comparisons.

The mean range of ND values for the climatic divisions included in the study decreased with decreased resolution (Figure 2). The range of ND values for the LAC data averaged above 0.5 while the range of the GVI2 data was below 0.25. The mean of the standard deviations of the ND values within the CD's (Table 5) ranged between 0.076 and 0.068 for the LAC, GAC, and GVI1 data, respectively. The GVI2 ND values, however, displayed standard deviations less than 0.057.

Similar to the weekly comparisons of LAC and GAC ND values per county, ND values computed weekly for climatic divisions were compared by data resolution (Table 6). The greatest differences in the LAC and GAC data of the CD's, as was observed in the county analysis, occurred in week 11 when the mean difference was 0.01. Differences in LAC and GAC ND values greater than 0.001 existed for all of the weeks examined in the study. Differences in LAC and GVI ND values greater than 0.001 were observed for four of the five weeks examined.

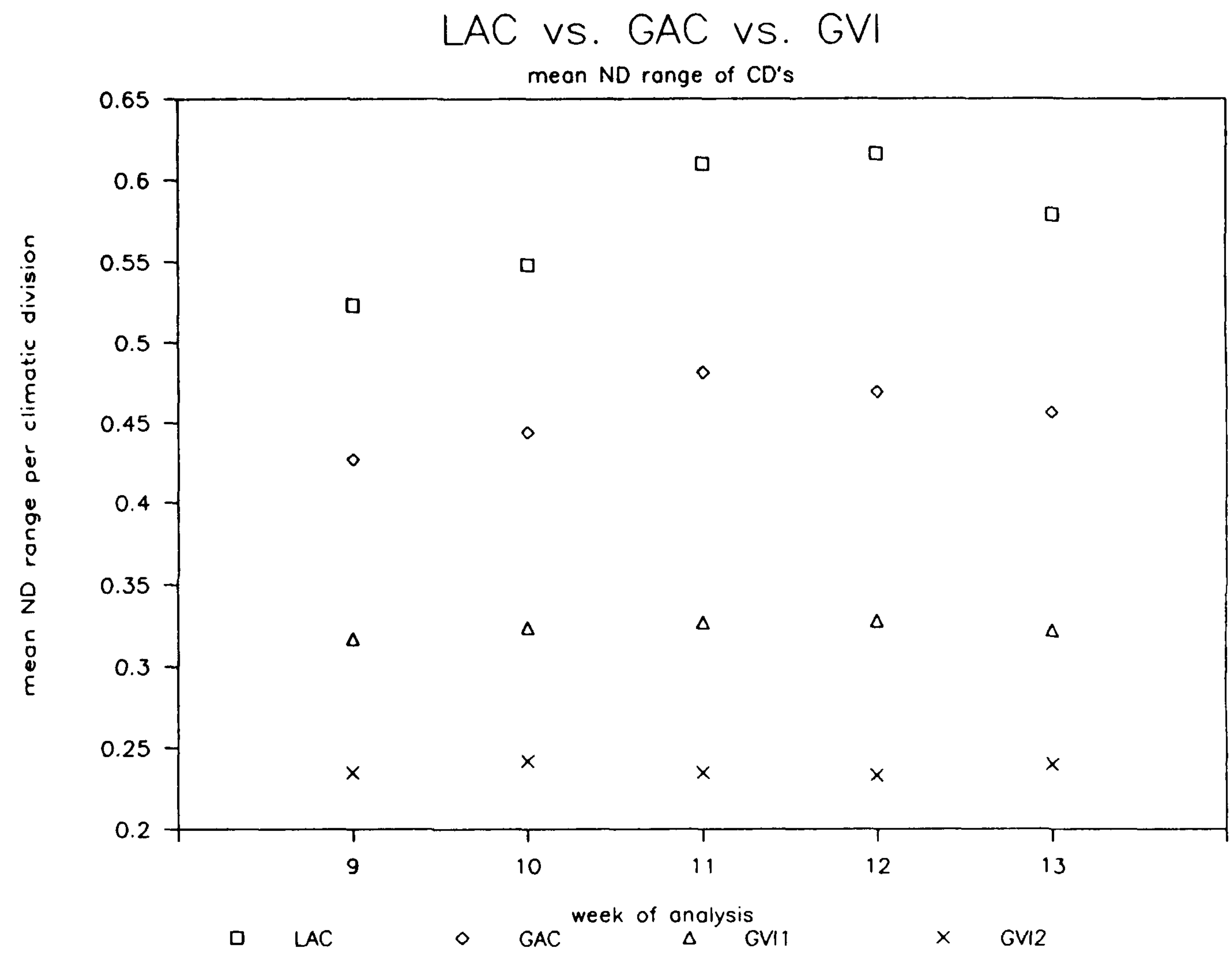

Figure 2. Mean range of ND values for the climatic divisions included in the study, by week, for the LAC, GAC, GVI1, and GVI2 data.

Table 5. Weekly comparisons of ND values of LAC, GAC, GVI1, and GVI2 resolutions for the climatic divisions included in the study (n=70).

week	sample	mean climatic division ND values			
		max	min	mean	s
9	LAC	.56	.03	.29	.073
	GAC	.50	.07	.29	.069
	GVI1	.45	.13	.29	.068
	GVI2	.41	.17	.29	.054
10	LAC	.62	.07	.36	.074
	GAC	.56	.11	.35	.070
	GVI1	.51	.18	.35	.069
	GVI2	.47	.23	.35	.056
11	LAC	.59	-.02	.31	.073
	GAC	.51	.03	.30	.069
	GVI1	.46	.13	.30	.069
	GVI2	.42	.18	.30	.054
12	LAC	.59	-.02	.31	.076
	GAC	.53	.06	.30	.070
	GVI1	.47	.14	.30	.070
	GVI2	.43	.20	.31	.054
13	LAC	.58	.00	.29	.074
	GAC	.52	.06	.29	.070
	GVI1	.46	.14	.29	.070
	GVI2	.42	.18	.29	.055

The difference in reduced resolution estimates of ND due solely to shifts in the boundaries associated with the reduced resolution is demonstrated in the comparison of mean ND values for GAC and GVI2 (Table 6). GVI2 was computed as the mean of all GAC pixels within the GVI coverage area. The only difference between the two estimates for a given CD would be inclusion of some data at the GAC resolution in one CD while in an adjacent CD at the GVI resolution. The difference in mean ND values due to boundary shifts that occur with reduced resolution could account for a substantial amount of the differences observed between various resolutions of data (e.g. differences greater for GAC vs. GVI2 than GAC vs. GVI1). Although small differences in the

ND data of the various resolutions exist from week to week, the changes in the mean ND values within a CD are similar at all resolutions (Figure 3). All four examined resolutions displayed similar week-to-week fluctuations within the randomly selected CD.

Table 6. Results of weekly comparisons of ND values of LAC, GAC, and GVI resolutions for the climatic divisions included in the study (n=70).

samples compared	mean ND difference ($X 10^2$) by week of analysis				
	9	10	11	12	13
LAC vs. GAC	.120	.350	1.000	.240	.170
LAC vs. GVI1	.004	.369	1.080	.266	.176
LAC vs. GVI2	-.013	.288	.997	.160	.128
GAC vs. GVI1	-.117	.017	.009	.025	.003
GAC vs. GVI2	-.134	-.065	-.024	-.082	-.042

Data Compositing

Twelve sites of varied vegetation types were selected for analysis of the data compositing algorithms (Table 7). Visible and near-IR data for a five by five pixel sample was computed for each site for each day included in the composite week. Each composite week included Saturday through Sunday observations to match the weekly time interval utilized in production of the NOAA GVI product. Daily satellite images were visually screened for cloud free observations prior to selection for inclusion in the weekly composite. Daily values of the Normalized Difference (ND) and Difference (DIFF) vegetation indices were computed and recorded with the satellite zenith angle (Table 8). Visible and near-IR reflectance data associated with the weekly observed maximum values of the ND and DIFF indices were retained for each site together with the satellite zenith angle data. ND values were computed for each composite week and site based on the visible and near-IR data selected

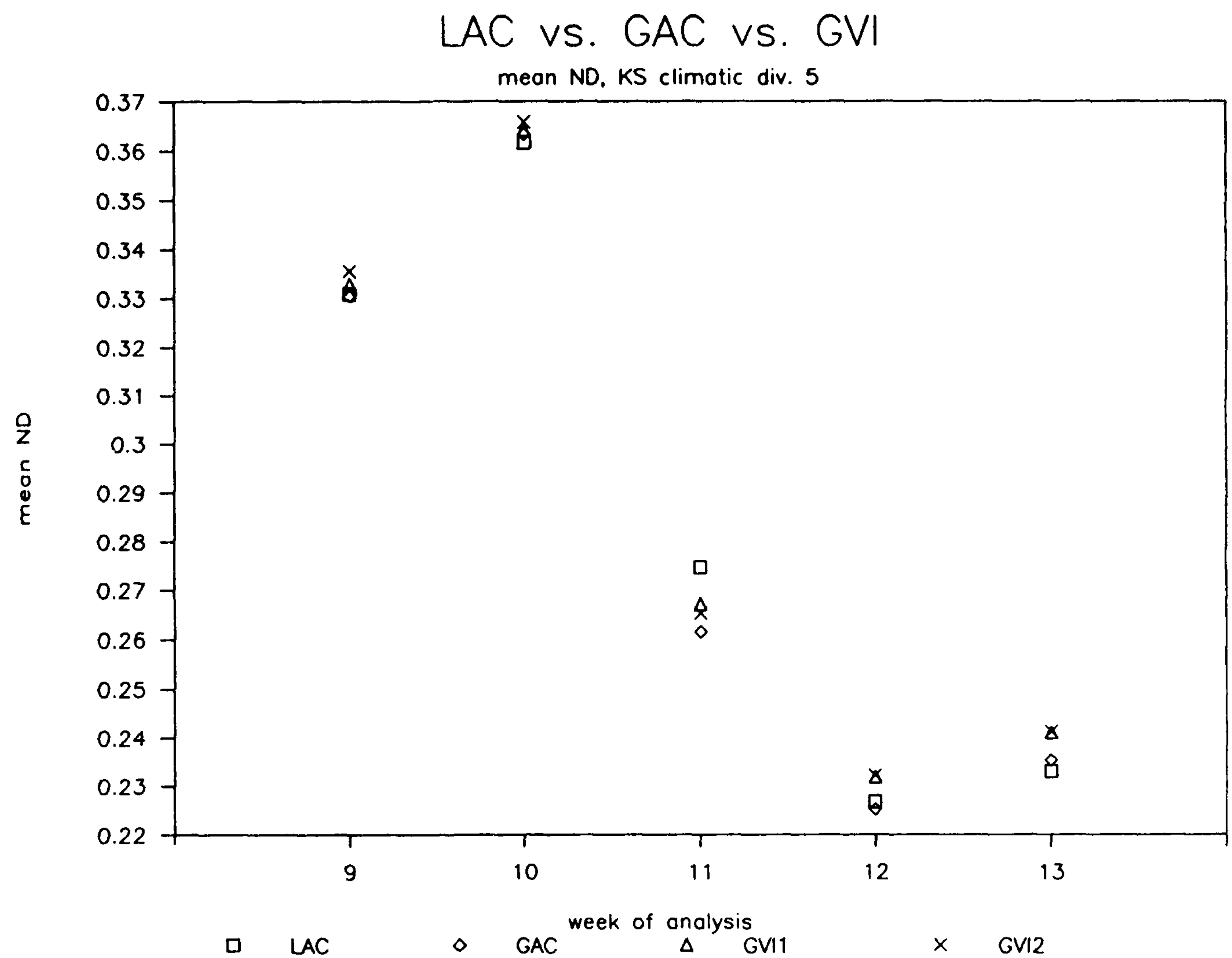

Figure 3. Mean LAC, GAC, GVI1, and GVI2 ND values for the five weeks of the study for climatic division No. 5 in Kansas.

Table 7. Study locations for compositing algorithm analyses.

Site	Lat. (^{o}N)	Long. (^{o}W)	State/ Province	Vegetation Type
1	48.3	102.6	ND	Crop/Grassland
2	46.3	103.1	ND	Crop/Grassland
3	44.2	101.2	SD	Grazing/Grassland
4	43.0	95.7	IA	Crop
5	37.2	94.6	KS	Crop/Grassland
6	46.2	103.1	ND	Crop/Grassland
7	46.7	95.2	MN	Forest/Crop
8	48.8	94.3	ONT	Forest
9	41.4	95.7	IA	Crop
10	41.2	97.9	NE	Crop
11	40.5	98.2	NE	Crop
12	42.4	105.7	WY	Forest

by the maximum ND and DIFF values. The selection criteria, for composite week 9 of Site 3 (Table 8), resulted in selection of ND values of .29 (based on maximum ND) and .26 (based on maximum value of DIFF). Satellite zenith angles selected were 48^{o} (positive number indicated forward scatter direction, negative indicates backscatter) based on the ND, and -35^{o} based on the DIFF algorithm. ND values for Site 3, computed from visible and near-IR data selected by the maximum weekly ND algorithm, were consistently greater than those computed from data selected by the maximum weekly DIFF algorithm (Figure 4). Satellite zenith angles selected, based on the DIFF algorithm were predominantly from the backscatter direction while those selected with the ND algorithm were selected from both forward and backscatter directions.

Satellite zenith angles selected by the DIFF and ND composite algorithms for seven of the twelve sites examined in this study differed for greater than half of the observed weeks (Table 9). The similarity of scan angle selection by the two algorithms was as great as 80% for the 10 composite weeks examined due primarily to cloud contamination of ground observations through most of the composite interval. The similarity of selected angles was as low as 20% of those weeks evaluated (Site 6, Table 9).

ND values computed from the weekly DIFF composites were less than or equal to the values computed based on the ND composites due to the systematic satellite zenith (SZ) angle selection by the two indices. Negative SZ angles present a backscatter view and resulted in lower ND values than the near-nadir or forward scatter views favored by the ND composite algorithm (Figure 4). The DIFF composite algorithm

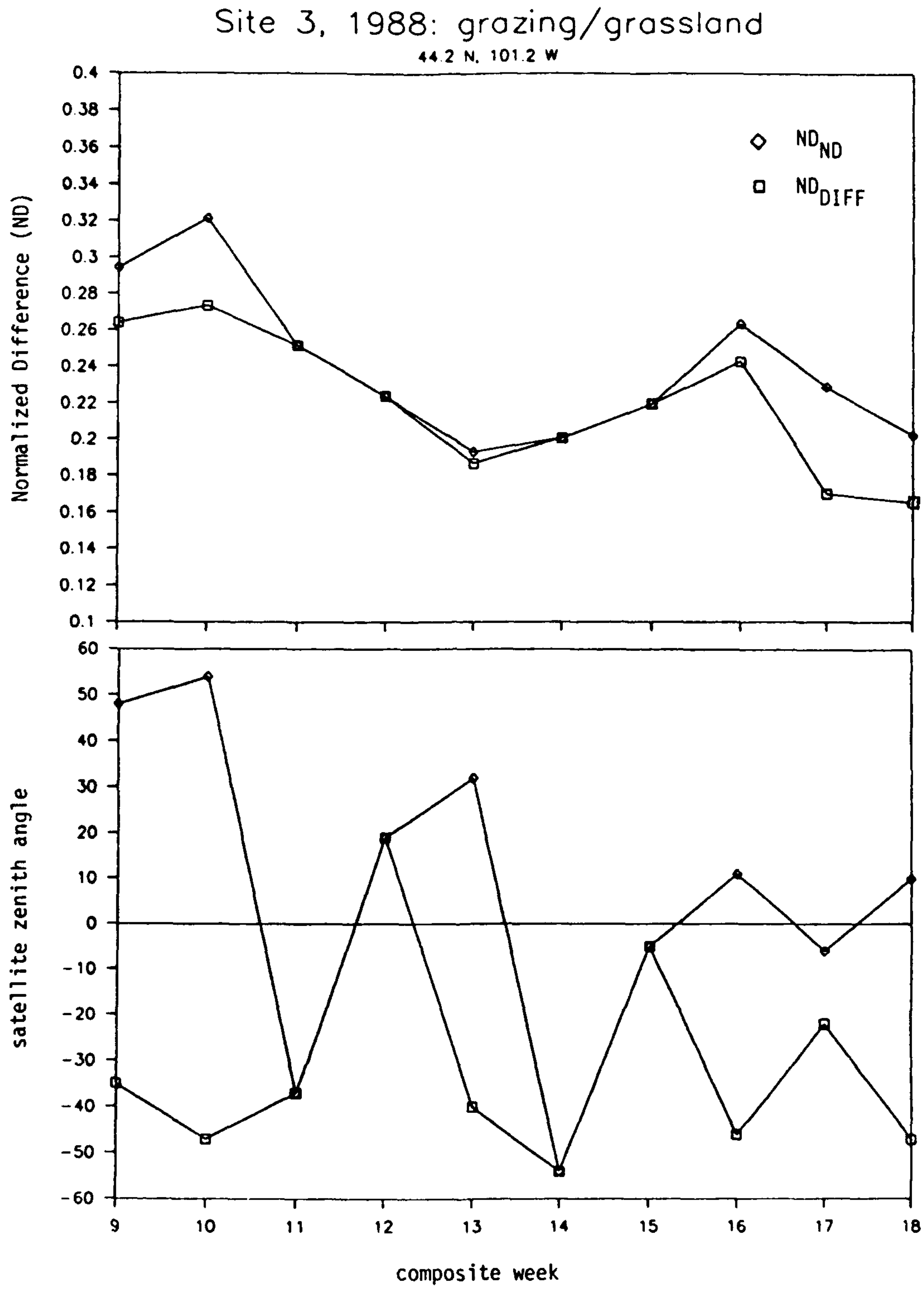

Figure 4. Weekly composited ND values and associated satellite zenith angles based on the ND (ND_{ND}) and DIFF (ND_{DIFF}) composite algorithms.

Table 8. Daily visible (vis), near-IR (nIR), ND, DIFF, and satellite zenith angle (satzen) values for site 3.

Site 3: 44.2°N, 101.2°W (Grazing/Grassland)

date	composite week	vis	nIR	ND	DIFF	satzen
May 25	9	6.20	10.75	0.27	4.55	38.00
26	9	5.75	10.55	0.29	4.80	48.00
29	9	8.00	13.75	0.26	5.75	-35.00
June 2	10	11.00	14.75	0.15	3.75	24.00
3	10	7.05	12.10	0.26	5.05	36.00
4	10	9.25	13.20	0.18	3.95	46.00
5	10	5.75	11.20	0.32	5.45	54.00
6	10	9.70	17.00	0.27	7.30	-47.00
7	11	8.70	14.55	0.25	5.85	-37.00
8	11	7.50	11.55	0.21	4.05	-24.00
9	11	6.90	10.00	0.18	3.10	-9.00
18	12	15.45	18.85	0.10	3.40	-11.00
19	12	6.15	9.55	0.22	3.40	4.00
20	12	5.90	9.30	0.22	3.40	19.00
21	13	6.90	10.20	0.19	3.30	32.00
25	13	9.70	14.15	0.19	4.45	-40.00
26	13	8.50	12.10	0.17	3.60	-28.00
28	14	21.65	23.60	0.04	1.95	-2.00
July 3	14	10.75	16.15	0.20	5.40	-54.00
4	14	9.80	14.15	0.18	4.35	-34.00
6	15	27.20	28.50	0.02	1.30	-21.00
7	15	6.75	10.55	0.22	3.80	-5.00
13	16	8.95	14.70	0.24	5.75	-46.00
15	16	5.85	9.60	0.24	3.75	-22.00
16	16	6.05	9.60	0.23	3.55	-6.00
17	16	5.30	9.10	0.26	3.80	11.00
23	17	36.60	38.60	0.03	2.00	-36.00
24	17	9.60	13.55	0.17	3.95	-22.00
25	17	6.30	10.05	0.23	3.75	-6.00
26	18	6.00	9.05	0.20	3.05	10.00
27	18	10.00	12.20	0.10	2.20	-26.00
31	18	10.05	14.05	0.17	4.00	-47.00

consistently, for the 12 study sites analyzed (Table 9, Figure 5), selected negative (backscatter) SZ angles when cloud free observations were available. The ND composite algorithm usually selected SZ angles nearer to a nadir view than the DIFF, however, large SZ angles in the forward scatter were occasionally selected by the ND algorithm over angles (positive or negative) nearer to nadir. Large forward scatter SZ angles, for example, were selected by the ND algorithm over the nearer-to-nadir angles selected by the DIFF index for weeks 9 and 10 of Sites 2 and 3 (Table 9).

Table 9. Visible (vis), near-IR (nIR), normalized difference (ND), and difference (DIFF) vegetation index values selected for the 10 weeks and 12 sites included in the study. Data selection was based on the weekly maximum ND and DIFF composite values.

Site 1 (48.3 N, 102.6 W)			ND composite				DIFF composite					
date	week	vis	nIR	ND	DIFF	satzen	date	vis	nIR	ND	DIFF	satzen
May 25	9.00	5.75	11.50	0.33	5.75	35.00	May 29	7.95	14.25	0.28	6.30	-34.00
June 3	10.00	5.15	11.00	0.36	5.85	33.00	June 6	9.65	16.80	0.27	7.15	-45.00
9	11.00	6.80	11.40	0.25	4.60	-9.00	7	8.45	14.15	0.25	5.70	-35.00
19	12.00	5.80	11.35	0.32	5.55	2.00	18	6.60	12.45	0.31	5.85	-11.00
21	13.00	5.20	10.05	0.32	4.85	29.00	26	7.75	13.20	0.26	5.45	-27.00
July 3	14.00	9.60	18.10	0.31	8.50	-52.00	July 3	9.60	18.10	0.31	8.50	-52.00
7	15.00	5.35	12.00	0.38	6.65	-6.00	7	5.35	12.00	0.38	6.65	-6.00
13	16.00	7.65	17.60	0.39	9.95	-44.00	13	7.65	17.60	0.39	9.95	-44.00
23	17.00	7.55	15.40	0.34	7.85	-35.00	23	7.55	15.40	0.34	7.85	-35.00
26	18.00	5.30	10.40	0.32	5.10	8.00	31	8.80	15.50	0.28	6.70	-46.00
			x̄ =	0.33	6.47	-3.90			x̄ =	0.31	7.01	-33.50
			s =	0.04	1.67	30.09			s =	0.05	1.33	14.31

Site 2 (46.3 N, 103.1 W)			ND composite				DIFF composite					
date	week	vis	nIR	ND	DIFF	satzen	date	vis	nIR	ND	DIFF	satzen
May 25	9.00	6.70	11.30	0.26	4.60	40.00	May 29	8.00	13.45	0.25	5.45	-30.00
June 4	10.00	5.90	12.35	0.35	6.45	48.00	June 6	9.50	16.60	0.27	7.10	-42.40
7	11.00	8.35	15.00	0.28	6.65	-31.80	7	8.35	15.00	0.28	6.65	-31.80
19	12.00	5.90	11.10	0.31	5.20	9.00	19	5.90	11.10	0.31	5.20	9.00
21	13.00	6.10	11.45	0.30	5.35	35.00	25	9.30	14.90	0.23	5.60	-35.00
July 3	14.00	13.45	18.70	0.16	5.25	-50.00	July 3	13.45	18.70	0.16	5.25	-50.00
7	15.00	5.90	10.55	0.28	4.65	2.00	7	5.90	10.55	0.28	4.65	2.00
13	16.00	9.40	15.00	0.23	5.60	-41.00	13	9.40	15.00	0.23	5.60	-41.00
25	17.00	7.00	10.70	0.21	3.70	0.00	24	7.80	11.60	0.20	3.80	-16.00
26	18.00	12.50	15.60	0.11	3.10	16.00	26	12.50	15.60	0.11	3.10	16.00
			x̄ =	0.25	5.06	2.72			x̄ =	0.23	5.24	-21.92
			s =	0.07	1.05	32.54			s =	0.06	1.13	22.15

Site 3 (44.2 N, 101.2 W)			ND composite				DIFF composite					
date	week	vis	nIR	ND	DIFF	satzen	date	vis	nIR	ND	DIFF	satzen
May 26	9.00	5.75	10.55	0.29	4.80	48.00	May 29	8.00	13.75	0.26	5.75	-35.00
June 5	10.00	5.75	11.20	0.32	5.45	54.00	June 6	9.70	17.00	0.27	7.30	-47.00
7	11.00	8.70	14.55	0.25	5.85	-37.00	7	8.70	14.55	0.25	5.85	-37.00
20	12.00	5.90	9.30	0.22	3.40	19.00	21	5.90	9.30	0.22	3.40	19.00
21	13.00	6.90	10.20	0.19	3.30	32.00	25	9.70	14.15	0.19	4.45	-40.00
July 3	14.00	21.50	16.15	0.20	5.40	-54.00	July 3	10.75	16.15	0.20	5.40	-54.00
7	15.00	6.75	10.55	0.22	3.80	-5.00	7	6.75	10.55	0.22	3.80	-5.00
17	16.00	5.30	9.10	0.26	3.80	11.00	13	8.95	14.70	0.24	5.75	-46.00
25	17.00	6.30	10.05	0.23	3.75	-6.00	24	9.60	13.55	0.17	3.95	-22.00
26	18.00	6.00	9.05	0.20	3.05	10.00	31	10.05	14.05	0.17	4.00	-47.00
			x̄ =	0.24	4.26	7.20			x̄ =	0.22	4.97	-31.40
			s =	0.04	0.97	32.64			s =	0.04	1.17	21.57

Table 9 (cont.)

Site 4 (43.0 N, 95.7 W)

ND composite date	week	vis	nIR	ND	DIFF	satzen	DIFF composite date	vis	nIR	ND	DIFF	satzen
May 25	9.00	4.90	7.95	0.24	3.05	15.00	May 25	4.90	7.95	0.24	3.05	15.00
June 5	10.00	4.60	9.25	0.34	4.65	39.00	June 6	9.00	16.70	0.30	7.70	-61.00
9	11.00	6.90	14.05	0.34	7.15	-35.00	9	6.90	14.05	0.34	7.15	-35.00
20	12.00	4.50	12.25	0.46	7.75	-8.00	18	7.10	15.15	0.36	8.05	-36.10
21	13.00	4.25	12.50	0.49	8.25	7.40	25	7.50	21.90	0.49	14.40	-56.00
July 4	14.00	7.45	20.90	0.47	13.45	-60.00	4	7.45	20.90	0.47	13.45	-60.00
6	15.00	6.05	19.50	0.53	13.45	-44.00	6	6.05	19.50	0.53	13.45	-44.00
16	16.00	5.00	19.10	0.59	14.10	-34.00	13	7.50	22.10	0.49	14.60	-61.00
25	17.00	4.75	18.25	0.59	13.50	-34.00	23	7.10	21.75	0.51	14.65	-54.00
26	18.00	4.25	16.40	0.59	12.15	-20.00	31	8.05	20.80	0.44	12.75	-62.00
			$\bar{x}$ =	0.46	9.75	-17.36			$\bar{x}$ =	0.42	10.93	-45.41
			s =	0.12	3.87	28.85			s =	0.09	3.88	22.38

Site 5 (37.2 N, 94.6 W)

ND composite date	week	vis	nIR	ND	DIFF	satzen	DIFF composite date	vis	nIR	ND	DIFF	satzen
May 25	9.00	3.60	13.50	0.58	9.90	21.00	May 26	3.80	14.20	0.58	10.40	36.00
June 5	10.00	4.30	13.70	0.52	9.40	45.00	June 6	8.50	19.40	0.39	10.90	-62.00
9	11.00	6.50	16.55	0.44	10.05	-33.00	9	6.50	16.55	0.44	10.05	-33.00
19	12.00	5.90	13.70	0.40	7.80	-20.00	19	5.90	13.70	0.40	7.80	-20.00
21	13.00	5.40	12.50	0.40	7.10	14.00	21	5.40	12.50	0.40	7.10	14.00
July 4	14.00	8.25	15.60	0.31	7.35	-61.00	July 4	8.25	15.60	0.31	7.35	-61.00
7	15.00	6.40	15.20	0.41	8.80	-31.00	7	6.40	15.20	0.41	8.80	-31.00
13	16.00	8.00	17.30	0.37	9.30	-62.00	13	8.00	17.30	0.37	9.30	-62.00
24	17.00	7.25	16.20	0.38	8.95	-45.00	24	7.25	16.20	0.38	8.95	-45.00
26	18.00	4.60	13.65	0.50	9.05	-16.00	31	7.85	18.35	0.40	10.50	-62.00
			$\bar{x}$ =	0.43	8.77	-18.80			$\bar{x}$ =	0.41	9.12	-32.60
			s =	0.08	0.97	33.80			s =	0.07	1.29	32.55

Site 6 (46.2 N, 103.1 W)

ND composite date	week	vis	nIR	ND	DIFF	satzen	DIFF composite date	vis	nIR	ND	DIFF	satzen
May 26	9.00	7.70	13.20	0.26	5.50	50.10	May 26	7.70	13.20	0.26	5.50	50.10
June 4	10.00	6.15	12.20	0.33	6.05	49.00	June 5	6.70	13.05	0.32	6.35	56.00
7	11.00	8.55	14.80	0.27	6.25	-30.00	7	8.55	14.80	0.27	6.25	-30.00
19	12.00	6.60	11.55	0.27	4.95	11.20	19	6.60	11.55	0.27	4.95	11.20
21	13.00	7.20	12.40	0.27	5.20	37.00	21	7.20	12.40	0.27	5.20	37.00
July 3	14.00	10.65	16.85	0.23	6.20	-50.00	July 3	10.65	16.85	0.23	6.20	-50.00
7	15.00	5.80	11.20	0.32	5.40	2.00	7	5.80	11.20	0.32	5.40	2.00
13	16.00	8.90	15.55	0.27	6.65	-41.00	13	8.90	15.55	0.27	6.65	-41.00
24	17.00	7.10	11.60	0.24	4.50	-16.00	24	7.10	11.60	0.24	4.50	-16.00
26	18.00	6.90	10.90	0.22	4.00	16.00	31	10.15	14.75	0.18	4.60	-42.00
			$\bar{x}$ =	0.27	5.47	2.83			$\bar{x}$ =	0.24	5.05	-2.06
			s =	0.03	0.80	34.53			s =	0.08	1.74	35.93

Table 9 (cont.)

Site 7 (46.7 N, 95.2 W)			ND composite				DIFF composite					
date	week	vis	nIR	ND	DIFF	satzen	date	vis	nIR	ND	DIFF	satzen
May 25	9.00	5.15	12.90	0.43	7.75	-4.00	May 29	10.10	21.55	0.36	11.45	-61.00
June 6	10.00	8.60	22.20	0.44	13.60	-66.00	June 6	8.60	22.20	0.44	13.60	-66.00
9	11.00	7.10	20.70	0.49	13.60	-46.00	7	8.90	22.90	0.44	14.00	-61.00
20	12.00	5.60	14.80	0.45	9.20	-24.00	19	6.55	17.30	0.45	10.75	-37.00
25	13.00	8.95	22.35	0.43	13.40	-62.00	26	10.40	24.45	0.40	14.05	-56.00
July 3	14.00	12.60	19.90	0.22	7.30	-67.00	July 3	12.60	19.90	0.22	7.30	-67.00
7	15.00	8.80	18.70	0.36	9.90	-39.00	7	8.80	18.70	0.36	9.90	-39.00
16	16.00	7.00	17.50	0.43	10.50	-40.00	13	9.35	21.50	0.39	12.15	-63.00
24	17.00	8.50	19.65	0.40	11.15	-50.00	24	8.50	19.65	0.40	11.15	-50.00
26	18.00	6.30	14.90	0.41	8.60	-29.00	31	9.00	18.75	0.35	9.75	-64.00
			$\bar{x}$ =	0.41	10.50	-42.70			$\bar{x}$ =	0.38	11.41	-56.40
			s =	0.07	2.27	19.04			s =	0.06	2.04	10.34

Site 8 (48.8 N, 94.3 W)			ND composite				DIFF composite					
date	week	vis	nIR	ND	DIFF	satzen	date	vis	nIR	ND	DIFF	satzen
May 26	9.00	4.75	9.65	0.34	4.90	2.00	May 26	4.75	9.65	0.34	4.90	2.00
June 5	10.00	3.30	12.20	0.57	8.90	16.00	June 6	7.50	20.05	0.46	12.55	-68.00
9	11.00	6.00	21.50	0.56	15.50	-50.00	8	7.25	25.10	0.55	17.85	-58.00
20	12.00	4.30	15.75	0.57	11.45	-31.00	19	5.15	17.00	0.53	11.85	-42.00
21	13.00	3.90	13.60	0.55	9.70	-18.00	26	7.40	22.15	0.50	14.75	-59.00
28	14.00	13.70	23.15	0.26	9.45	-44.00	28	13.70	23.15	0.26	9.45	-44.00
July 7	15.00	6.10	17.95	0.49	11.85	-44.00	July 6	6.50	18.60	0.48	12.10	-52.00
17	16.00	4.60	16.25	0.56	11.65	-35.00	13	7.35	19.90	0.46	12.55	-65.00
24	17.00	8.35	15.40	0.30	7.05	-53.00	23	11.65	19.50	0.25	7.85	-60.00
27	18.00	3.75	13.35	0.56	9.60	-23.00	31	7.95	18.35	0.40	10.40	-65.00
			$\bar{x}$ =	0.48	10.01	-28.00			$\bar{x}$ =	0.42	11.43	-51.10
			s =	0.12	2.74	21.54			s =	0.10	3.40	19.53

Site 9 (41.4 N, 95.7 W)			ND composite				DIFF composite					
date	week	vis	nIR	ND	DIFF	satzen	date	vis	nIR	ND	DIFF	satzen
May 25	9.00	5.75	11.55	0.34	5.80	12.00	May 25	5.75	11.55	0.34	5.80	12.00
June 5	10.00	5.40	12.60	0.40	7.20	40.00	June 6	10.10	20.25	0.33	10.15	-65.00
9	11.00	8.05	16.90	0.35	8.85	-40.00	9	8.05	16.90	0.35	8.85	-40.00
20	12.00	5.60	12.80	0.39	7.20	-11.00	18	7.35	16.00	0.37	8.65	-42.00
26	13.00	8.50	21.20	0.43	12.70	-52.00	26	8.50	21.20	0.43	12.70	-52.00
July 4	14.00	8.20	21.70	0.45	13.50	-60.00	July 4	8.20	21.70	0.45	13.50	-60.00
7	15.00	5.90	17.50	0.50	11.60	-30.00	6	6.60	18.70	0.48	12.10	-43.00
16	16.00	5.00	17.95	0.56	12.95	-32.00	13	8.10	21.20	0.45	13.10	-60.00
25	17.00	4.90	18.60	0.58	13.70	-32.00	25	7.05	22.15	0.52	15.10	-53.00
26	18.00	4.30	16.20	0.58	11.90	-17.00	31	8.30	21.60	0.44	13.30	-61.00
			$\bar{x}$ =	0.46	10.54	-22.20			$\bar{x}$ =	0.42	11.33	-46.40
			s =	0.09	2.83	28.42			s =	0.06	2.71	21.18

Table 9 (cont.)

Site 10 (41.2 N, 97.9 W)			ND composite				DIFF composite					
date	week	vis	nIR	ND	DIFF	satzen	date	vis	nIR	ND	DIFF	satzen
May 26	9.00	7.25	11.35	0.22	4.15	39.00	May 26	7.20	11.35	0.22	4.15	39.00
June 5	10.00	5.25	10.70	0.34	5.45	49.00	June 6	9.60	16.30	0.26	6.70	-60.00
9	11.00	6.30	11.70	0.30	5.40	-29.00	7	8.35	15.40	0.30	7.05	-52.00
20	12.00	4.45	10.25	0.39	5.80	3.00	18	6.80	13.35	0.33	6.55	-31.00
26	13.00	6.70	16.80	0.43	10.10	-44.00	26	6.70	16.80	0.43	10.10	-44.00
July 4	14.00	7.20	18.75	0.45	11.55	-55.00	July 4	7.20	18.75	0.45	11.55	-55.00
6	15.00	5.20	16.10	0.51	10.90	-33.00	6	5.20	16.10	0.51	10.90	-33.00
15	16.00	5.05	18.00	0.56	12.95	-33.00	13	6.80	20.95	0.51	14.15	-55.00
25	17.00	4.05	15.10	0.58	11.05	-19.00	23	6.45	18.75	0.49	12.30	-47.00
26	18.00	3.50	13.65	0.59	10.15	-2.00	31	7.40	19.95	0.46	12.55	-56.00
			$\bar{x}$ =	0.44	8.75	-12.40			$\bar{x}$ =	0.39	9.60	-39.40
			s =	0.12	3.02	32.77			s =	0.10	3.10	27.72

Site 11 (40.5 N, 98.2 W)			ND composite				DIFF composite					
date	week	vis	nIR	ND	DIFF	satzen	date	vis	nIR	ND	DIFF	satzen
May 25	9.00	6.75	15.50	0.39	8.75	28.00	May 25	6.75	15.50	0.39	8.75	28.00
June 5	10.00	5.15	14.40	0.47	9.25	51.00	June 5	5.15	14.40	0.47	9.25	51.00
7	11.00	8.20	16.85	0.35	8.65	-51.00	7	8.20	16.85	0.35	8.65	-51.00
20	12.00	5.40	12.15	0.38	6.75	7.00	18	7.50	14.80	0.33	7.30	-29.00
21	13.00	5.45	12.55	0.39	7.10	23.00	26	8.20	17.20	0.35	9.00	-42.00
July 4	14.00	8.20	17.50	0.36	9.30	-54.00	July 4	8.20	17.50	0.36	9.30	-54.00
6	15.00	6.65	14.80	0.38	8.15	-30.00	6	6.65	14.80	0.38	8.15	-30.00
17	16.00	4.50	12.50	0.47	8.00	-45.00	13	8.25	17.90	0.37	9.65	-54.00
25	17.00	5.05	13.50	0.46	8.45	1.00	23	8.30	17.40	0.35	9.10	-33.00
27	18.00	4.20	12.30	0.49	8.10	-55.00	31	8.85	18.00	0.34	9.15	-56.00
			$\bar{x}$ =	0.41	8.25	-12.50			$\bar{x}$ =	0.37	8.83	-27.00
			s =	0.05	0.79	37.24			s =	0.04	0.64	35.01

Site 12 (42.4 N, 105.7 W)			ND composite				DIFF composite					
date	week	vis	nIR	ND	DIFF	satzen	date	vis	nIR	ND	DIFF	satzen
May 26	9.00	7.50	11.30	0.20	3.80	61.00	May 25	11.30	15.55	0.16	4.25	54.00
June 6	10.00	5.60	12.90	0.39	7.30	-35.00	June 6	5.60	12.90	0.39	7.30	-35.00
7	11.00	4.40	10.00	0.39	5.60	-20.00	7	4.40	10.00	0.39	5.60	-20.00
19	12.00	3.40	7.60	0.38	4.20	30.00	18	3.50	7.75	0.38	4.25	13.00
25	13.00	5.15	10.75	0.35	5.60	-22.00	25	5.15	10.75	0.35	5.60	-22.00
July 4	14.00	5.85	12.70	0.37	6.85	-24.00	July 4	5.85	12.70	0.37	6.85	-24.00
7	15.00	5.45	9.90	0.29	4.45	27.00	7	5.45	9.90	0.29	4.45	27.00
17	16.00	3.70	8.70	0.40	5.00	39.00	13	5.25	10.40	0.33	5.15	-25.00
23	17.00	4.45	8.70	0.32	4.25	-9.00	23	4.45	8.70	0.32	4.25	-9.00
27	18.00	10.80	14.50	0.15	3.70	49.00	27T	10.80	14.50	0.15	3.70	49.00
			$\bar{x}$ =	0.33	5.08	9.60			$\bar{x}$ =	0.31	5.14	0.80
			s =	0.08	1.18	33.34			s =	0.09	1.14	30.98

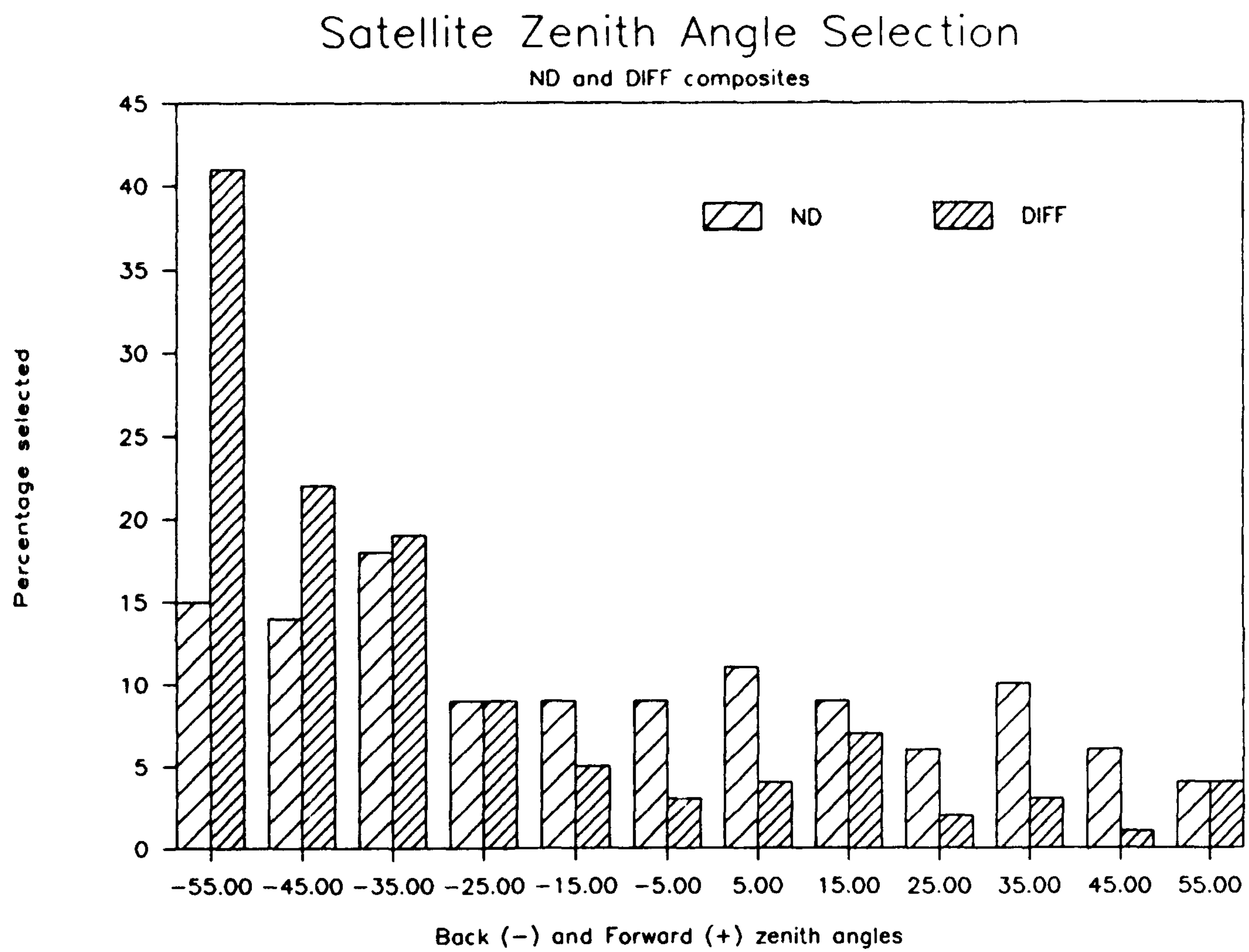

Figure 5. Satellite zenith angle selection based on maximum ND and DIFF composites for the 12 sites and 10 weeks evaluated (n=120).

IV. CONCLUSIONS AND RECOMMENDATIONS

Spatial averaging of satellite derived data reduces data processing expenses, computer processing time, and data storage requirements. Thus, increased spatial analysis is possible when low compared to high resolutions of data are utilized. Comparisons of county and climatic division averages of the various resolutions of data indicated that differences existed between the examined resolutions and sampling algorithms included in this study, however, a portion of the difference was not due to the reduction of the resolution of the satellite data but to shifts in county and climatic division boundaries as a result of data reduction.

GAC resolution data provided essentially the same values as LAC for the spatial areas associated with U.S. counties in the Great Plains region (average area 2,817 km^2). Similarly, for the areas associated with the examined climatic divisions (average area 21,825 km^2) GVI1, GVI2, and GAC data provided essentially the same values as LAC. Vegetation index data derived for the climatic divisions computed with the GVI1 algorithm were more representative of the LAC and GAC data than were the VI data computed with the GVI2 algorithm. The overall results of this study suggest that NOAA continues to use the current algorithm for GVI data reduction compared to an average of all GAC samples within a GVI pixel.

The DIFF composite algorithm consistently, for the 12 study sites analyzed, selected negative (backscatter) SZ angles when possible. The ND composite algorithm usually selected SZ angles nearer to a nadir view than the DIFF, however, large SZ angles in the forward scatter were occasionally selected by the ND algorithm over angles (positive or negative) nearer to nadir.

In summary, while differences existed between the vegetation index values computed for the examined data resolutions when computed over specific spatial areas, the mean values of the low resolution data were representative of the full resolution data, and if utilized in monitoring activities, would likely provide the similar results. The ND and DIFF algorithms, utilized in data compositing, each displayed deficiencies as selectors of near-nadir views of land surface features. The simple difference would be the recommended algorithm for satellite zenith angle selection if advantages exist for selection of backscatter views of vegetation from satellites.

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